

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) 09-02-2012		2. REPORT TYPE Conference Proceeding		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Multi- and Hyperspectral Ocean Color Measurements from Long Island Sound Observation Platform (LISCO): Comparison with Satellite Measurements and Assessments of Uncertainties				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER 0601153N	
				5d. PROJECT NUMBER	
6. AUTHOR(S) S. Ahmed, Robert Amone, A. Gilerson, T. Harmel, S. Hlaing, Alan Weidemann				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER 73-9435-D0-5	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory Oceanography Division Stennis Space Center, MS 39529-5004				8. PERFORMING ORGANIZATION REPORT NUMBER NRL/PP/7330-10-0429	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research One Liberty Center 875 North Randolph Street, Suite 1425 Arlington, VA 22203-1995				10. SPONSOR/MONITOR'S ACRONYM(S) ONR	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution is unlimited.					
13. SUPPLEMENTARY NOTES <div style="text-align: right; font-size: 2em; margin-top: 10px;">20120213025</div>					
14. ABSTRACT <p>The Long Island Sound Coastal Observational platform (LISCO) near Northport, New York, has been recently established to support satellite data validation. LISCO is equipped with both multispectral SeaPRISM and hyperspectral HyperSAS radiometers for ocean color measurements. LISCO substantially expands observational capabilities for the continuous monitoring and assessment of the ocean color satellite data quality. These expanded capabilities offer a potential for improving calibration and validation activities for the current and future Ocean Color satellite missions, as well as for satellite inter-comparison and spectral characterization of coastal waters. Results of measurements obtained from both instruments, in operation since October 2009, are presented, evaluated and compared with ocean color satellite data. This comparison with normalized water-leaving radiance derived from SeaPRISM and from MERIS, MODIS and SeaWiFS showed satisfactory correlations ($r > 0.9$ at 550nm) and consistencies ($APD < 15\%$ at 550nm). These results demonstrated that the use of the LISCO site is appropriate for calibration/validation of ocean color satellites in coastal waters, and as a key element of the AERONET-OC network. It is thus possible to envisage wider use of LISCO site to monitor current and future ocean color multispectral (NPOESS, Sentinel...) and hyperspectral (HICO) satellite missions.</p>					
15. SUBJECT TERMS coastal water, multispectral, hyperspectral, validation, calibration, satellite					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 8	19a. NAME OF RESPONSIBLE PERSON Robert Amone
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code) 228-688-5268

Multi- and Hyperspectral Ocean Color Measurements from Long Island Sound Observation Platform (LISCO): Comparison with Satellite Measurements and Assessments of Uncertainties

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ABSTRACT

The Long Island Sound Coastal Observational platform (LISCO) near Northport, New York, has been recently established to support satellite data validation. LISCO is equipped with both multispectral SeaPRISM and hyperspectral HyperSAS radiometers for ocean color measurements. LISCO substantially expands observational capabilities for the continuous monitoring and assessment of the ocean color satellite data quality. These expanded capabilities offer a potential for improving calibration and validation activities for the current and future Ocean Color satellite missions, as well as for satellite inter-comparison and spectral characterization of coastal waters. Results of measurements obtained from both instruments, in operation since October 2009, are presented, evaluated and compared with ocean color satellite data. This comparison with normalized water-leaving radiance derived from SeaPRISM and from MERIS, MODIS and SeaWiFS showed satisfactory correlations ($r > 0.9$ at 550nm) and consistencies (APD < 15% at 550nm). These results demonstrated that the use of the LISCO site is appropriate for calibration/validation of ocean color satellites in coastal waters, and as a key element of the AERONET-OC network. It is thus possible to envisage wider use of LISCO site to monitor current and future ocean color multispectral (NPOESS, Sentinel...) and hyperspectral (HICO) satellite missions.

Keywords: coastal water, multispectral, hyperspectral, validation, calibration, satellite

INTRODUCTION

Advances in oceanic bio-optical processes are expected to be more heavily focused on improving satellite retrieval products of inherent optical properties (IOP) of coastal waters, which, because of their complexity, offer more challenges than open ocean waters, where satellite observations and retrieval algorithms are already reasonably effective. Thus, the validation of the current and future Ocean Color satellite data is important for characterizing the optical environment connected with coastal waters, which are of importance because of their vicinity to population concentrations and susceptibility to anthropogenic impacts. To address these concerns and support present and future multi- and hyper-spectral calibration/validation activities, as well as the development of new measurement and retrieval techniques and algorithms for coastal waters, City College (CCNY) along with Naval Research Laboratory at Stennis Space Center, has established a new, scientifically comprehensive, off-shore platform, the Long Island Sound Coastal Observatory (LISCO). This site has been designed to serve as a venue and framework for combining multi- and hyperspectral radiometer measurements with satellite and *in situ* measurements and radiative transfer simulations of coastal waters, helping to and provide more effective closure for the whole measurement validation/simulation loop. Measurements from the platform are utilized for multi-spectral calibration/validation of current Ocean Color satellites (MERIS, MODIS, SeaWiFS) in coastal waters, and for evaluating future

satellites missions (NPOESS, OCM2, Sentinel 2) with extension to hyperspectral calibration/validations of the hyperspectral sensors (HICO), as well as for improvements in coastal IOP retrieval and atmospheric correction algorithms.

The platform combines an AERONET SeaPRISM radiometer (CIMEL ELECTRONIQUE, France) as a part of AERONET Ocean Color Network (Zibordi, Mélin et al. 2004), with a co-located HyperSAS (Satlantic, Canada) set of radiometers capable of hyperspectral measurements of water-leaving radiance, sky radiance and downwelling irradiance. Both instruments were installed on the Long Island Sound Coastal Observatory (LISCO) in October 2009 and since then have been providing data. SeaPRISM data are transferred by the satellite link to NASA, processed by the NASA AERONET group and posted on the NASA AERONET website. HyperSAS data are transmitted by broadband cellular service to the CCNY server. The LISCO site is located ~2 miles from the shore on the oil offloading platform which belongs to the power generation company, National Grid. The coordinates of the site are N 40°57'16", W 73°20'30" with an elevation of 12m. The instruments are positioned on a retractable tower on the platform (Figure 1).



Figure 1. Retractable tower with SeaPRISM and HyperSAS instruments on the LISCO platform.

WATER PARAMETERS IN THE AREA NEAR THE PLATFORM

Analysis of area water characteristics were done from MODIS–Aqua satellite data, processed using SeaDAS software v.5.0.3 with the standard atmospheric correction. Average chlorophyll concentration [Chl] values in the pixels in the immediate vicinity of the platform were found to be: 3-8 mg/l. Backscattering coefficients are in the range $0.01-0.02 \text{ m}^{-1}$, which assuming a backscattering ratio of 1% corresponds to about 1-2 mg/l of Total Suspended Solids. Non algal absorption, mostly due to CDOM for these TSS values, ranges from 0.1 to 0.3 m^{-1} , where, according to NOAA HF Radar data, surface currents in the area are $0.2-0.4 \text{ m/s}$. These values are typical of moderate coastal waters. Time series of water parameters in the platform vicinity show these to be typical for coastal water conditions, and the moderate variability observed, Figure 2, can be expected to help to establish robust relationships

between reflectance values and water parameters, facilitating application to satellite retrieval algorithms.

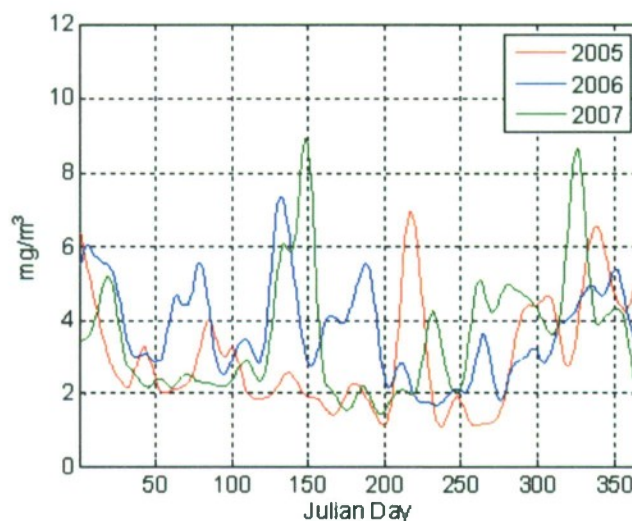


Figure 2. Time series of the chlorophyll concentration over the 2005-2007 period.

COMPARISONS OF SEAPRISM AND HYPERSAS

The main difficulty with above-water measurements is associated with correcting the observations for the effect of surface waves that introduce significant fluctuations into the glint and reflected skylight components (Hooker, Lazin et al. 2002). These fluctuations induce different geophysical noise to be removed from SeaPRISM and HYPERSAS sensors, respectively. Based on the retrieval scheme of SeaPRISM (Zibordi, Hooker et al. 2002), a specific processing has been developed in order to derive the normalized water-leaving radiance nLw from the HYPERSAS measurements.

The distributions of the water-leaving radiance, as measured by SeaPRISM and HYPERSAS, are displayed for the example of November 4th 2009 (Figure 3). This figure shows a satisfactory agreement between the SeaPRISM bands and the equivalent HYPERSAS wavelengths. In addition, HYPERSAS shows the existence of several hyperspectral patterns in nLw, which are obviously not sensed by SeaPRISM.

The comparison between HYPERSAS and SeaPRISM nLw datasets is plotted Figure 4 for the wavelengths centered on the SeaPRISM bands from October 2009 up to April 2010. The results show a strong correlation, with R^2 greater than 0.92, between the two datasets for all wavelengths. However, a few outliers are present, especially for the lowest values of nLw. This observation is consistent with errors originating from sky and sun glint corrections, for which absolute values are independent of nLw. Thus, the collocation of the two sensors enables us to assess the quality of different surface effect correction schemes over a long term monitoring period. This analysis is expected to be completed in the near future. In addition, the observed dispersion between the two datasets relies also on different techniques for measurements of atmospheric transmittance, and on the differences in bidirectionality corrections of nLw, because of the different observational geometries used by SeaPRISM and HYPERSAS. The satisfactory correlations shown Figure 4 demonstrate the consistency of the

processing for both instruments. The long term monitoring as well as the comparison with satellite data is expected to determine the representativeness of each technique.

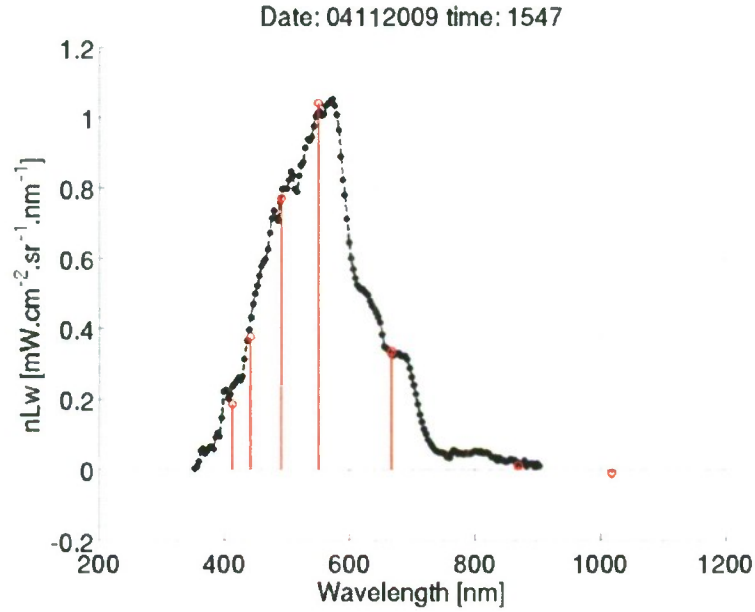


Figure 3. Examples of concomitant HYPERSAS (black dots) and SeaPRISM (red circles) data for November 4th 2010

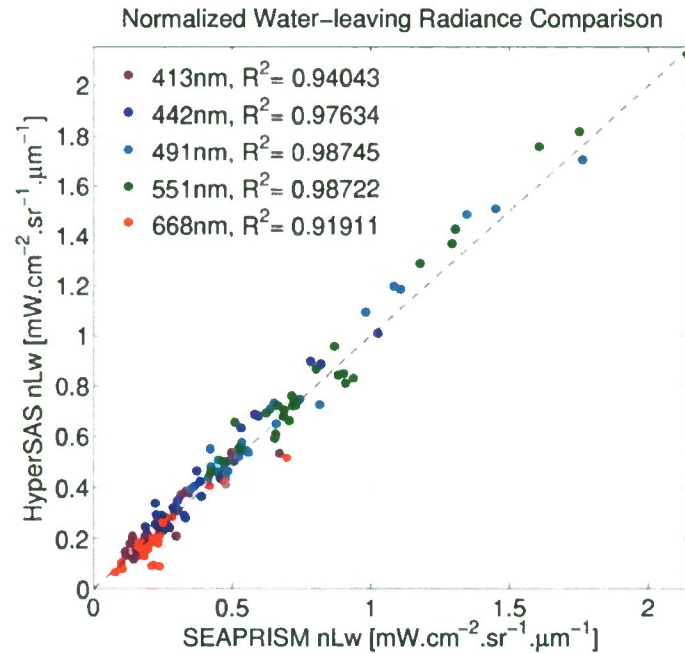


Figure 4. Scatter plot of the comparison between HYPERSAS and SeaPRISM datasets from October 2009 up to April 2010.

ASSESSMENT OF MERIS, MODIS AND SEAWIFS OCEAN COLOR PRODUCTS

An ideal site for the calibration/validation activity of satellite-derived parameters would provide ground truth data within a range and statistical distribution closely matching those of the satellite data. In the coastal areas, the oceanic and atmospheric parameters are very variable from site to site and can be expected to strongly impact the measurements from space. The appraisal of coastal satellite data relies on the use of numerous measurement sites so as to encompass the full natural variability. Therefore, to specifically determine whether the LISCO site meets objectives for validating coastal ocean color products, we have compared the distributions of the normalized water-leaving radiance nL_w at various center wavelengths in the visible and near-infrared spectral regions, derived from either satellite observations or from LISCO measurements. The objective of this study were not to carry out satellite validation in the strict sense of the word, but, rather, to assess how representative is the LISCO site as an element of the AERONET-OC network.

Thus, results are displayed for normalized water-leaving radiances derived from SeaPRISM measurements and MERIS, MODIS as well as SeaWiFS satellite data (Figure 5). In this figure, the time series covering the 9-months period from October 2009 is shown for several center wavelengths; with the satellite data interpolated to fit to SeaPRISM bands. The SeaPRISM data includes the values derived from quality-checked measurements (level 1.5) taken between 10:00 and 14:00 (local time) excluding the overcast conditions. For the comparison, the average and standard deviation values of the satellite data have been calculated within a $3\text{km} \times 3\text{km}$ area over the LISCO platform. The extreme southwest pixel corresponds to the nearest pixel to the platform. For the results for MERIS, the full resolution data processed by the NASA processing is used. For MODIS (Aqua) and SeaWiFS, Merged Local Area Coverage data from ocean color reprocessing 2009 is used. The quality flags (glint, cloud, high solar and viewing zenith angle, atmospheric correction failure) have been applied for filtering the satellite data; the average values are considered qualified for comparison with in situ data when at least 90% of the pixels are not affected by these standard flags. In addition, the data from images that contain more than 20% cloudy pixels in a radius of 10 km around the platform are eliminated for the purposes of comparison. The same procedures, along with the selection of the SeaPRISM data, for the corresponding time window of ± 45 minutes centered on the satellite overpass, have been used to plot the matchup comparisons (Figure 6).

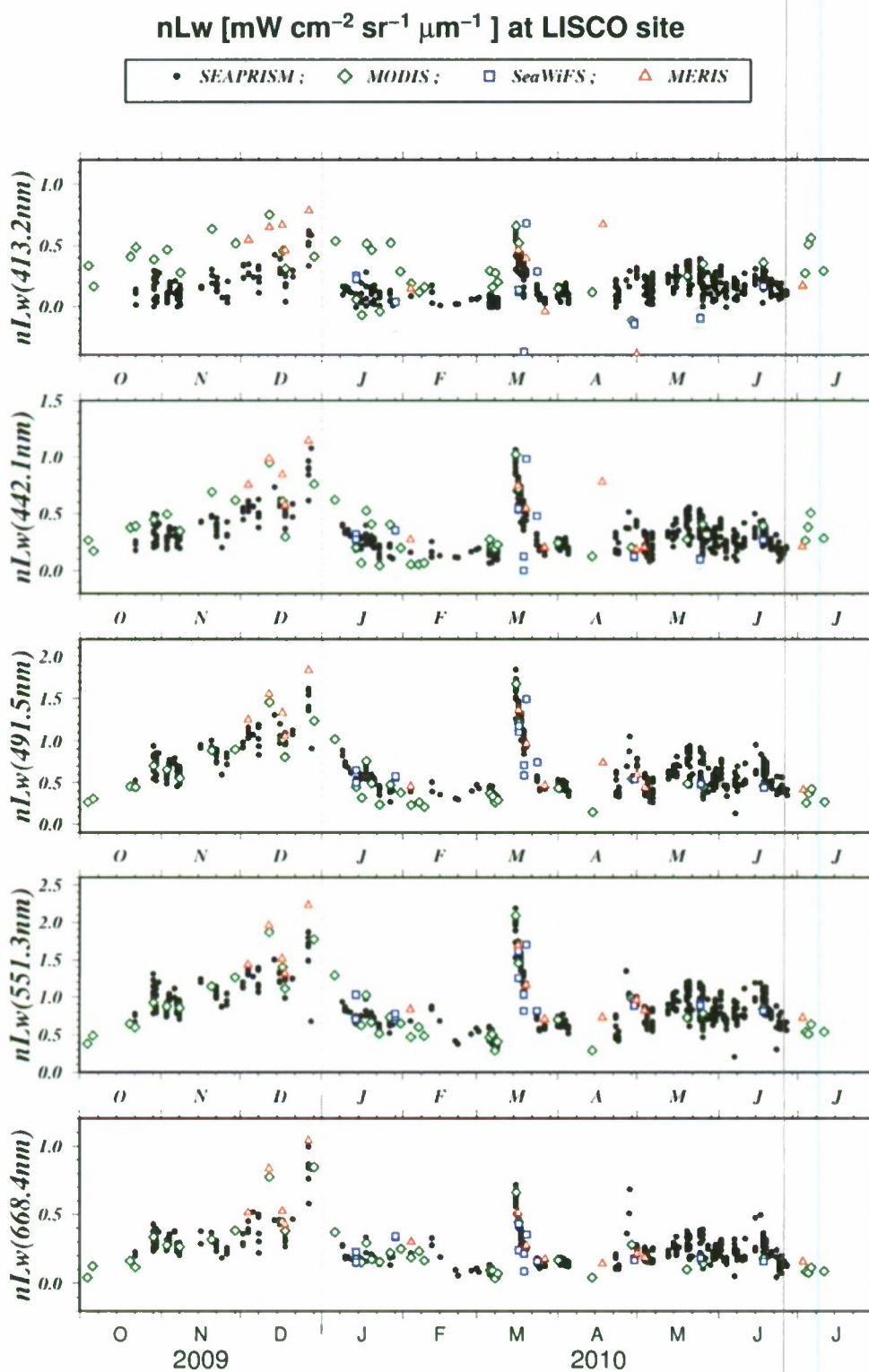


Figure 5. Time series of the normalized water-leaving radiance as measured by SeaPRISM (black dots), MERIS (red triangles), MODIS (green diamonds) and SeaWiFS (blue squares) at different wavelength in the visible spectrum.

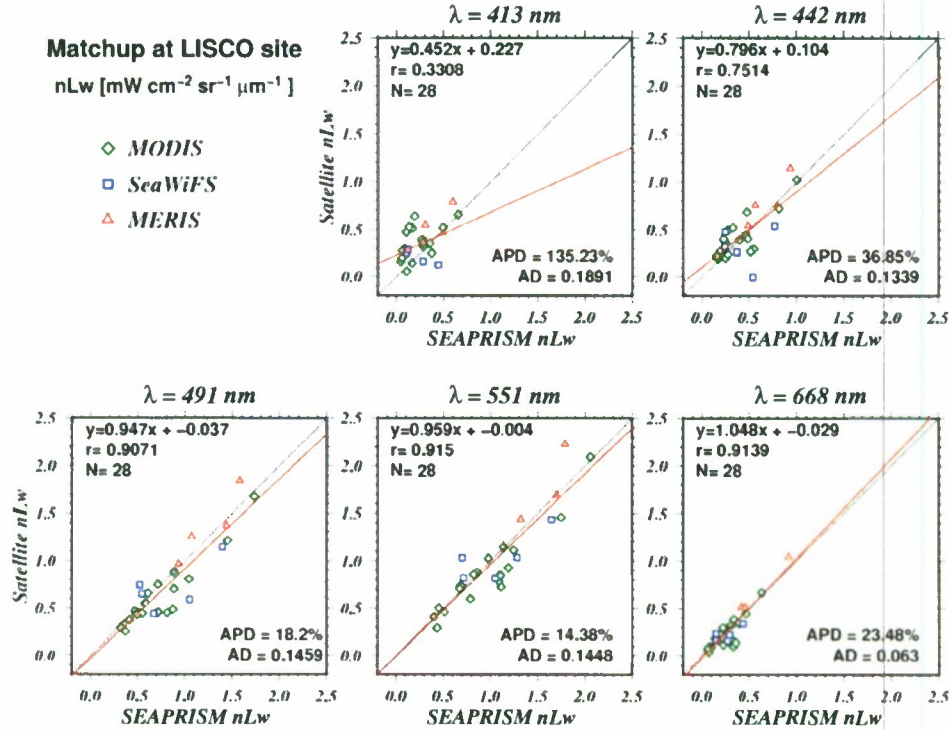


Figure 6. Scatter plots of the MERIS, MODIS and SeaWiFS match-ups with SEAPRISM normalized water-leaving radiance nLw at 413, 442, 491, 551 and 668 nm. The vertical bars correspond to ± 1 the standard deviation due to the pixel heterogeneity. N is the total number of points for each spectral match-up; r is correlation coefficient; APD and PD are the absolute percentage difference and the absolute difference, respectively. The red line is regression line.

The comparisons of match-up spectra and of their averages indicate qualitative agreement between SeaPRISM normalized water-leaving radiance and the corresponding ones derived from satellite data. The strong correlation coefficient obtained, demonstrates the validity of monitoring the nLw from space with values greater than 0.75 and 0.9 for the wavelength greater than 443nm and 490nm, respectively. In addition, the absolute percentage difference, APD,

$$APD = \frac{1}{N} \sum_{i=1}^N \frac{|x_i - y_i|}{x_i} \quad (1)$$

and the absolute difference, AD,

$$AD = \frac{1}{N} \sum_{i=1}^N |x_i - y_i| \quad (2)$$

with x taken for SeaPRISM data and y for satellite data, have been calculated in order to assess the consistency between satellite and SeaPRISM nLw. The AD and APD exhibit satisfactory values, with APD= 14% and AD 0.14 at 550 nm for example, consistent with similar studies (Zibordi, Berthon et al. 2009). On the other hand, the APD values show an increasing dispersion of the comparison in respect to the decreasing wavelengths. That dispersion is particularly large at 412 nm. Although this is

consistent with the known behavior of the atmospheric correction uncertainties, which increase from the red to the blue wavelengths, further analysis is needed to quantify the effect. The overall results presented for the LISCO nLw data are consistent with those obtained from similar validation exercises for coastal waters (Zibordi, Berthon et al. 2009) and to a lesser extent for an open ocean waters (Bailey and Werdell 2006; Antoine, d'Ortenzio et al. 2008). The study results confirmed that the LISCO site is a representative and appropriate element of the AERONET-OC network for calibration/validation activities of satellite-derived parameters in coastal waters.

CONCLUSION

The focus of this study was primarily to assess the ability of the collocated multi and hyperspectral instrumentations at the LISCO site to serve calibration/validation activities for satellite derived parameter in coastal areas. The LISCO instrumentation was described and representative water parameters in the platform vicinity were detailed. Second, the consistency between the HYPERSAS and SeaPRISM measurements was analyzed. The comparison of the related datasets showed a strong correlation throughout the wavelength range. Further analysis of data from long term monitoring is needed to assess how representative is each instrument. Finally, the distribution of the normalized water-leaving radiance measured by SeaPRISM was compared to that derived from the space-sensed data of MERIS, MODIS and SeaWiFS. This comparison showed satisfactory correlations ($r > 0.9$ at 550nm) and consistencies ($APD < 15\%$ at 550nm) comparable to the similar comparisons done for other sites of the AERONET-OC network. These results demonstrate that the LISCO site is appropriate as a key element of the AERONET-OC network for calibration/validation of the ocean color satellites in coastal waters. That makes it possible to envisage the wider use of the LISCO site for monitoring future ocean color multispectral (NPOESS, Sentinel...) and hyperspectral (HICO) satellite missions.

ACKNOWLEDGEMENT

This work was partially supported by grants from the Office of Naval Research and the National Oceanographic and Atmospheric Administration.

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